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Light collection for dummies:

in the spirit of the popular "…*for Dummies*" series, we present some rules of thumb based on many years of studying the problem for MINOS and NOvA.

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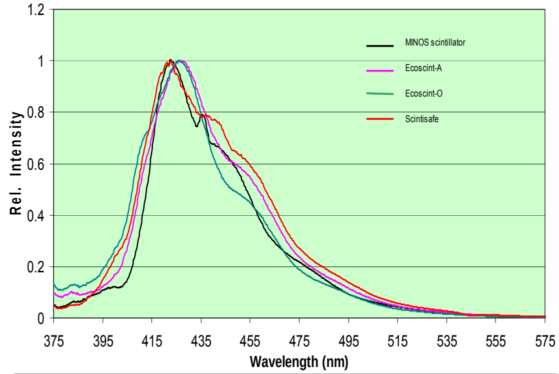
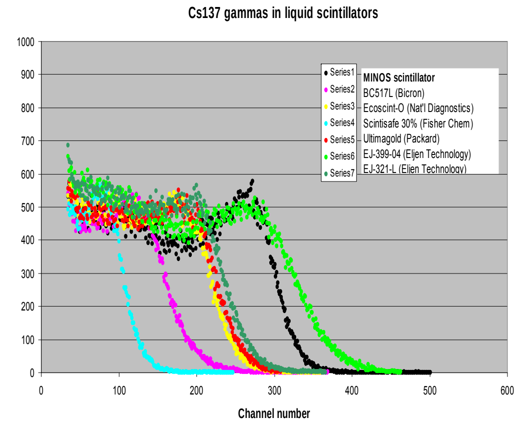
Scintillator emission spectra



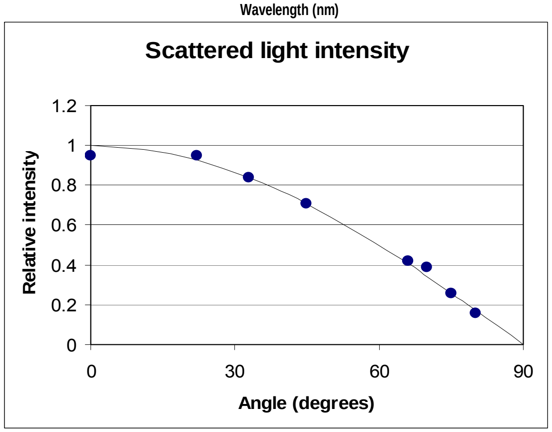


Light yields, oxygenated, relative to anthracene (1 photon/65 eV):

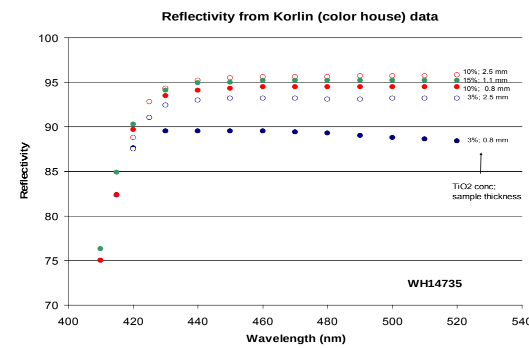
BC517P 21%

BC517L 30%

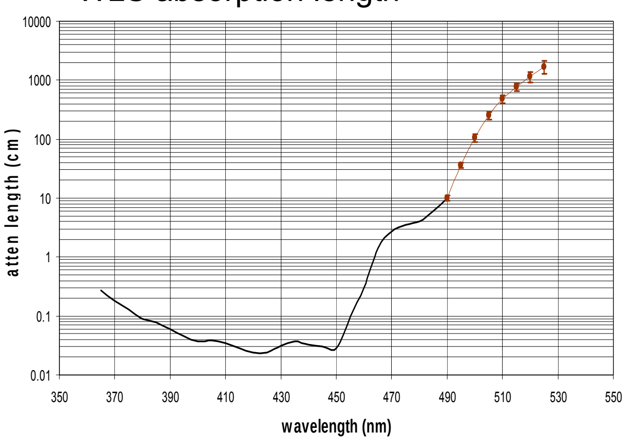
BC517H 40%

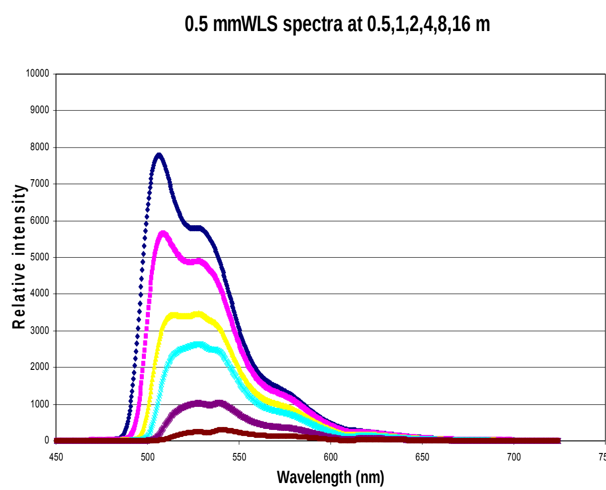


The Monte-Carlo for light collection contains many variables, some wavelength dependent. We have measured most.

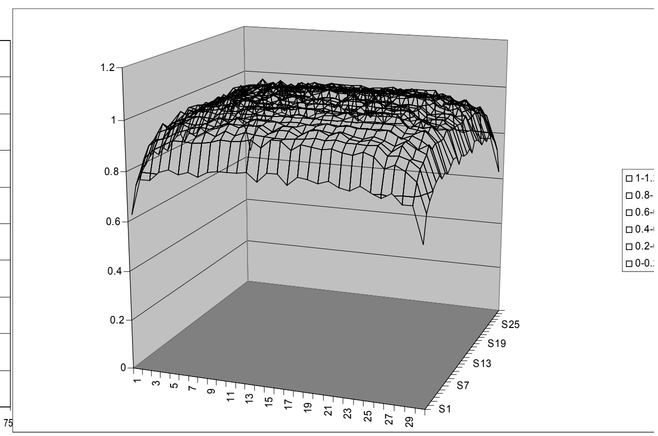


WLS absorption length





Light collection vs fiber position



How many bounces?

- After N reflections, wall reflectivity R:

  light remaining = $R^N = (1-A)^N \approx \exp(-NA)$

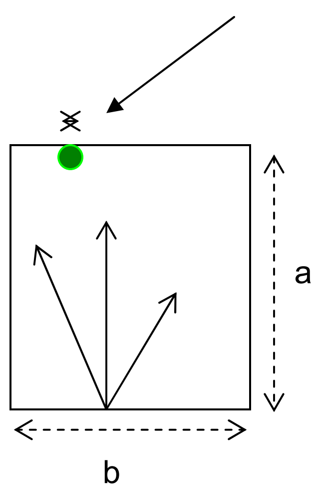
- (Note: Absorption coefficient should also include a small amount for absorption by fiber, i.e. $A \rightarrow A+d/w$)
- Average number of reflections:

$$\overline{N} = \frac{\int N \exp(-NA)dN}{\int \exp(-NA)dN} = \frac{1}{A}$$

- For R = (0.90,0.95) N = (10,20)

Probability of hitting a fiber between successive reflections

Fiber diameter *d*



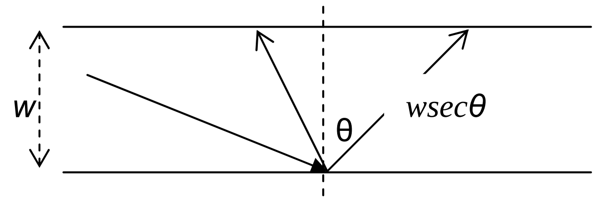
Average cell dimension ***w ~(a+b)/2***

<u>So probability is ~ *d/w*</u>

(Depends on angular distribution of reflected light and on geometry details)

N.B. Polyfluor outer layer of WLS fiber has n = 1.42, while scintillator has n = 1.50, so not all rays hitting fiber actually get inside, due to total internal reflection. (In MINOS geometry, abut 25% of the light is reflected, and another 25% is not absorbed due to short path length inside fiber, or to lack of absorption above ~ 455 nm)

Average distance traveled before absorption



- Reflection is diffuse (Lambert's law $dI/d\Omega = A\cos\theta$

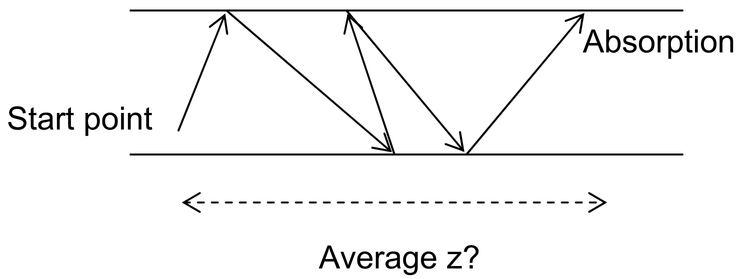
  $\rightarrow P(\theta)d\theta = \tfrac{1}{2}\cos\theta.d\cos\theta.$
- Average distance between reflections is:

  $\int w\sec\theta.\, P(\theta)d\theta \;= 2w$
- Average total distance = $2wN_{ave}$
- For $w \sim 5$ cm, $R = 0.90$ (10 bounces), distance ~ 100 cm

(This is an overestimate because we've just considered parallel walls)

<u>NOvA: 5 m atten. length in scintillator => 20% light loss!</u>

How far does light travel along a cell?



- **Average displacement of ray between reflections at opposite walls:**

$$\int w.\tan\theta.P(\theta)d\theta = \pi w/2$$

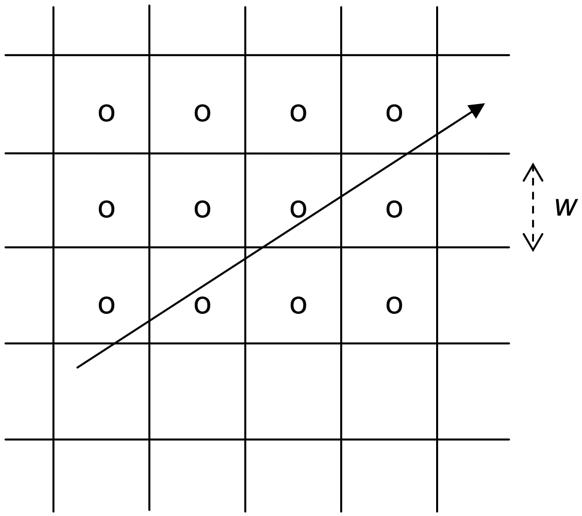
- **Need z-component only => × *by 1/√2***
- **Random walk => × by √N_{ave} bounces:**

$$\bar{z} \approx \frac{\pi w}{2}\sqrt{\frac{\bar{N}}{2}}$$

~ ±25 cm for w=5 cm, N=10

Another approach!

- If reflections were specular (?), could represent problem as a ray traveling through an array of cells



$$\frac{1}{\lambda_{total}} = \frac{1}{\lambda_{ref}} + \frac{1}{\lambda_{fib}} \quad ;\text{i.e.} \quad \frac{1}{\lambda_{total}} = \frac{A}{w} + \frac{d}{w^2}$$

mfp(fibs) = 1/nσ =(1/d)x(fibs/unit area)

mfp(abs) = 1/(absprob/unit distance)

- So, we have $\lambda_{total} = \dfrac{w}{A + \dfrac{d}{w}}$ **which is just the average (projected) distance traveled; x2 for actual distance**
  - **# bounces = λ/w**
  - **prob of hitting fiber $(1/\lambda_{fib})/(1/\lambda_{total})$ =** $\dfrac{1}{1 + \dfrac{Aw}{d}} \approx \dfrac{d}{Aw}$